LA ROSES

Laser Assisted RObotic Surgery of the anterior Eye Segment

Project full title:	Laser Assisted Robotic Surgery of the anterior Eye Segment
Project Acronym:	LA-ROSES
Grant Agreement number:	601116
Deliverable no.:	D4.1
Title:	Vision system development
Contractual Date of Delivery	Month 6
Actual Date of Delivery	September 21, 2016
Organization Short Name of Milestone Leading Partner	FAST
Organization Short Name of Other Participants	EKY, IFAC
Authors	Fabio Leoni, Bernardo Magnani, Francesca Rossi
Editors	Fabio Leoni, Bernardo Magnani, Francesca Rossi
Version	1.0
Tasks contributing to this deliverable	Task 4
Dissemination Level [1]	CO
Total number of pages (including cover page)	12

[1] Dissemination Level:

PU Public

PP Restricted to other programme participants (including the Commission Services)

RE Restricted to a group specified by the consortium (including the Commission Services)

CO Confidential, only for members of the consortium (including the Commission Services)

Version Management

Version	Date	Status	Author	Modification
1	10/01/2015	Setup	EKY	Creation of document
2	19/09/2016	Draft	FAST	Structure and initial content
3	20/09/2016	Draft	All partners	Revision/Comments
4	20/09/2016	Final	FAST	Final Revision

Summary

1 Executive Summary

This document reports the approach followed for the development of the LA-ROSES vision system in providing out images features used by the LA-ROSES robotic system to carry out (motor) actions for the execution of the laser welding procedure. The vision system HW is here briefly described because it is already described elsewhere but a description of image processing algorithms developed is given. The output of these image processing procedures are used by other LA-ROSES system controllers to realize the Visual Servoing control approach used by the overall controller to perform the corneal laser welding procedure.

2 Vision system output specifications

Taking into account the functional requirements described in paragraph 2 of D2.1 the design specifications of the LA-ROSES vision system are listed below:

- detection the boundary of the corneal tissue at the level of the wound. The boundary provides out the welding trajectory the welding-laser shall follows during the welding procedure;
- tracking the position of the welding laser spot during the welding procedure.

The above requirements consist of in providing specification of vision system outputs should be in order to allow the SW controller of the robotic system to carry out the following functionalities:

- enabling circular movement of a laser probe allowing a tracking of the circular path marked by the indocyanine solution
- enabling changing laser orientation, altitude from the corneal wound and tracking velocity during the welding procedure
- enabling initial gross and accurate positioning of the laser probe above the patient’s eye
- accurate laser probe positioning above the patient’s eye
- Through a control loop including the thermal camera, robot and laser intensity, a certain predefined temperature must be achieved on predefined points on the circle
- Demonstration of mitigation in dangerous scenario (e.g. Laser stops if temperature rises beyond certain limit, detected by the integrated thermal camera on end-effector).

3 Vision system set-up

The SW controller robotic system drives the robot movements and the movements of the LA-ROSES end-effector actuators which handles the laser, the NIR-camera and the thermal camera. The collected data provided out by the vision system allows the implementation of a Visual Servoing approach. As described elsewhere, VS, also known as vision-based robot control, is a technique which uses feedback information extracted from a vision sensor (visual feedback) to control the motion of a robotic system. The control law is based on the error between current and desired features on the image plane, and does not involve any estimate of the pose of the target. Error is computed directly on the values of the features extracted on the 2D image plane, without going through a 3D reconstruction. Using visual feedback to control a robot has been firstly introduced by Hutchinson et al. 1996. Thus, machine vision or image processing are part of the control system. Image processing techniques are required to acquire, filtrate and detect the target position inside images acquired by the camera(s) system(s). This sequence is repeated over the time enabling a tracking and control closed-loop scheme. Based on this sensory input, a control sequence is generated. In addition, the system may also require an automatic initialization which commonly includes figure–ground segmentation and object recognition. A typical visual servoing task uses image information to measure the error between the current location of the robot and its reference or desired location. Depending on the type of the task to be accomplished the measurement of the positioning error could be performed in the 3D or 2D space. 3D measurements generally requires a quite heavy computation burden in order to extract real word distances; on the contrary 2D applications usually requires error measurements computation directly in the image plane in order to reducing the image distance error between a set of current and desired image features in the image plane. The spatial relationship between the robotic arm and the vision system used could be very different in order to best fit the application requirements; some examples are eye-in-hand, stand alone (fixed) camera or their combination. In this project we use the former because of the camera is mounted aligned on the vertical of the end effector. The task consist of to allow the end effector to be aligned on the vertical of the patient eye as to detect and center the corneal wound. The corneal wound, to be treated by the welding-laser, appears as a circular cut which is enhanced by the application of a photo-enhancing dye solution to the tissue (see D2_1 for further details). To enable the detection of the circular wound we use an operator which seeks a circular path that is maximized when the change in the value of the pixels, varying the radius r and center (x0, y 0) of the circular outline. The operator is essentially a circular edge detector that shows a peak when a candidate circle has the same center and radius of the circular wound. The carried activities consists of the development of algorithms devoted to patient eye localization, filtering, segmentation, eye's structures identification and indocyanine laser welding path identification. Circular regression algorithms development in order to calculate the equation ellipse best fitting the real welding path (circular corneal wound).

The detection of the circular wound has to be performed taking into account the persistence of the laser spot onto the surface of the eye. In order to replicate a real appearance of the circular corneal cut a mock up consisting of a dressmaker's model head has been assembled as illustrated in figure 1.

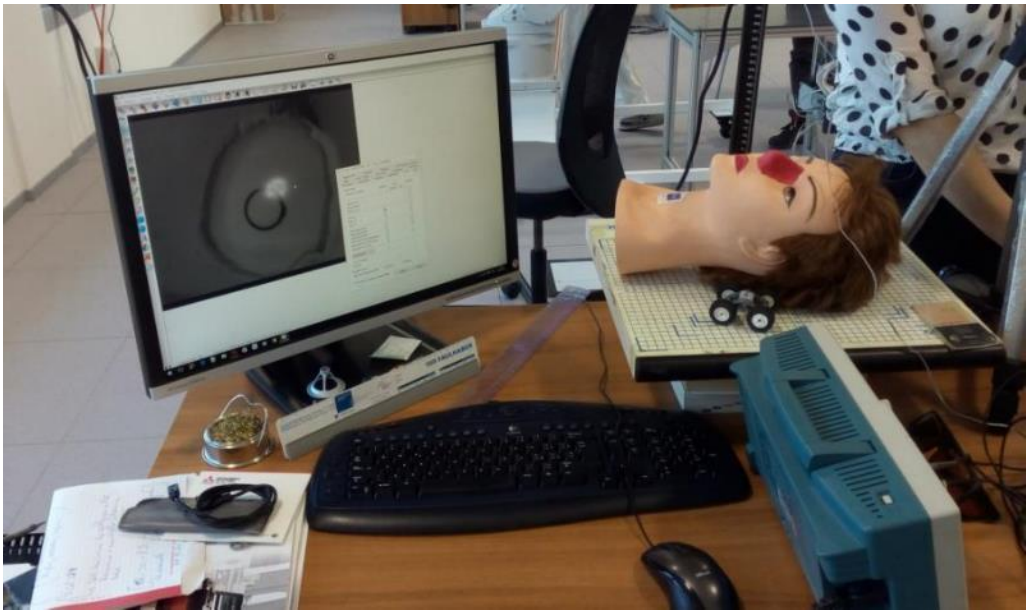


Figure 1 – a dressmaker's model head used as patient mock up. On the left an image of the patient eye representing the circular corneal wound; the laser spot is clearly visible.

The LA-ROSES laser module is a welding laser which has to be used very carefully due to the high powering output level (1 Watt) it can provide. Thus, for the development of images algorithms for the detection of the corneal wound and the detection of the laser spot we decided to use a low-power (1 mWatt) laser module emitting at the same wavelength of the LA-ROSES laser module. Figure 2 shows the laser used for this purpose.

Figure 2 – The laser module used for LA-ROSES image algorithms development. RS Components supply the laser.

Below follows Table 1 showing the laser characteristics

Parameter	RS stock no./Value				Units
	213-3562	213-3590	213-3584	213-3607	
Nominal wavelength	*635*	*670*	*635*	*670*	*nm*
Maximum power output	*1*	*0.8*	*3*	*3*	*mW*
Typical power output stability (@20°C)	*<3*				*%*
Typical power output temperature dependence	*15*				*μW/°C*
Operating voltage	*+4.5 to 5.5*				*Volts*
Typical operating current at minimum voltage	*65*				*mA*
Typical operating current at maximum voltage	*68*				*mA*
Power supply rejection ratio (50Hz-100kHz)	*1*				*%/V*
Mean time to failure (MTTF) @30°C	*4,500*	*20,000*	*4,500*	*20,000*	*Hours*
Connections	*2 pin socket (Pre wired plug supplied)*				
Red lead	*+ve supply*				
Green lead	*0*				*Volts*

Table 1 – Laser module specifications.

Also the dimension of the laser spot is comparable to those of the LA-ROSES laser module as figure 3 shows.

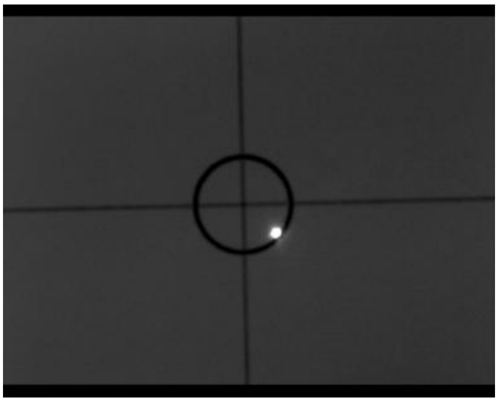


Figure 3 – the laser module provides out a spot whose dimension is the same of the LA-ROSES laser module.

Taking into account the LA-ROSES overall system diagram shown below in figure 4 for sake of comprehensiveness

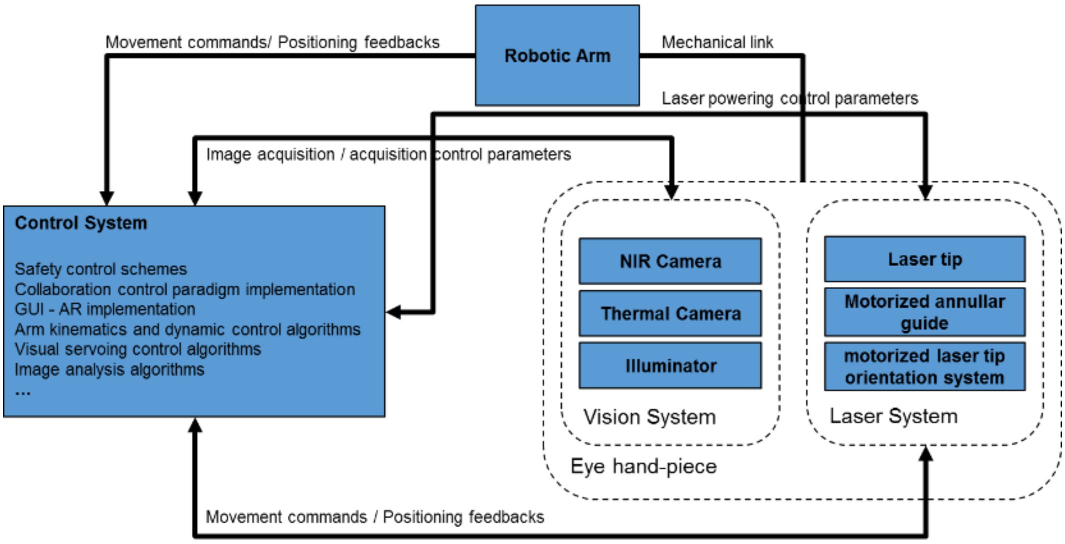


Figure 4 - LA-ROSES overall system diagram

The patient eye, the corneal wound and the laser spot have to be acquired by a NIR-camera handled by the robot. The NIR camera belong to the LA-ROSES end effector named “Eye hand-piece” and represented in figure 5.

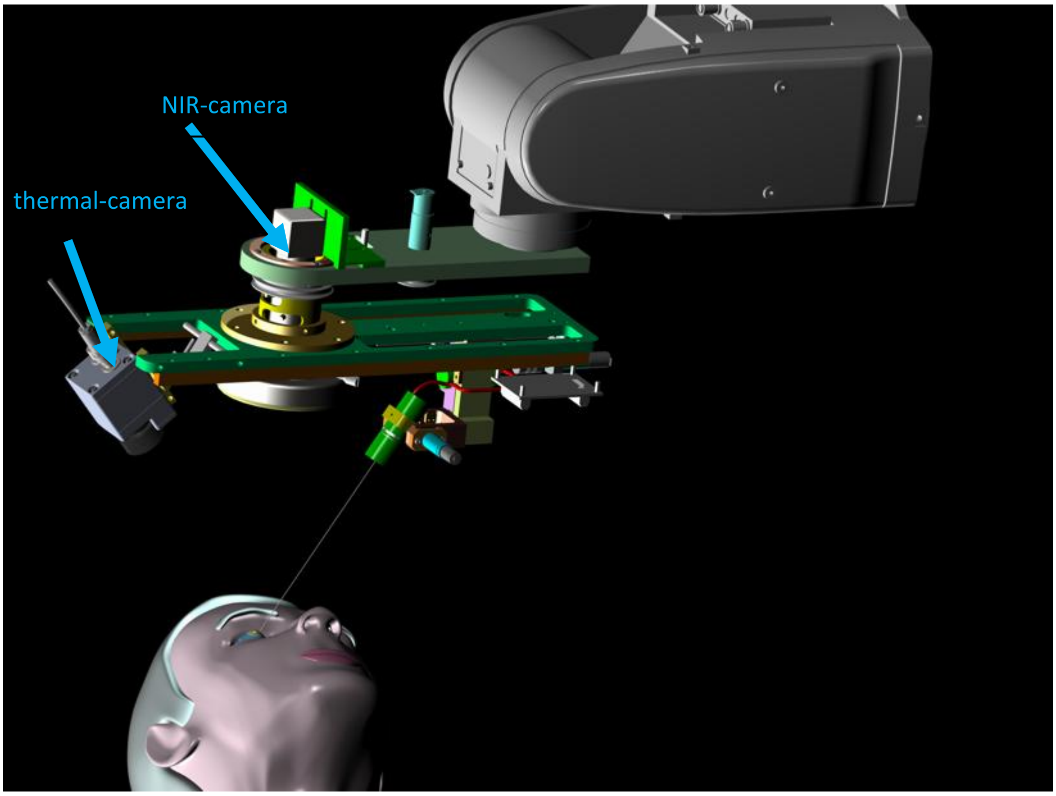
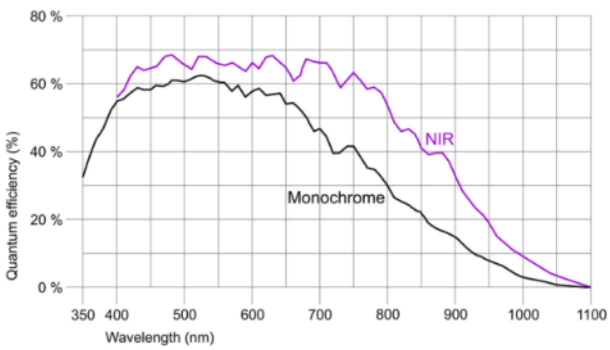


Figure 5 – The LA-ROSES “Eye hand-piece” end-effector and the positioning of the NIR-camera as to able to acquire in a single image the patient eye with the circular wound and the laser spot. The figure also contains the thermal camera here not described (see D5_1 for details).

The NIR-Camera used is the IDS UI-3240CP-NIR-GL



Sensor

Sensor type	CMOS Mono
Shutter	Global Shutter / Rolling shutter / Global Start Shutter
Sensor characteristic	Linear
Readout mode	Progressive scan
Pixel Class	SXGA
Resolution	1.31 Mpix
Resolution (h x v)	1280 x 1024 Pixel
Aspect ratio	5:4
ADC	10 bit
Color depth (camera)	12 bit
Sensor Size	1/1.8"
Optical Size	6.784 mm x 5.427 mm
Optical sensor diagonal	8.69 mm (1/1.84")
Pixel size	5.3 µm

c

LV3520
2/3"
35mm
F2.0
14.4° x 10.8°
0.2m
C-Mount
M 27 P= 0.5
34 x 36.535mm

d

Figure 6 – a) two view of the camera. b) the sensitivity response of the camera sensor. c) the camera specifications data. d) the camera lenses used.

We choose to use this particular camera because of its capability to be more sensitivity to NIR wavelengths than other monochrome cameras. This is useful to facilitate the detection and localization of the laser spot onto the surface of the patient's eye.

The LA-ROSES "Eye hand-piece" has been mounted as end-effector of a Mitsubishi RV-13FM robotic arm. On the contrary as described in D2_1 the arranged LA-ROSES robotic arm should have been the SCHUNK LightWeight Arm (LWA3). Unfortunately the LWA3 arm is not reliable because of we experienced a set of HW problems related to the electronic driver board mounted on joint 2 and 3. The new LA-ROSES robotic arm is therefore the Mitsubishi RV-13FM as shown in figure 7.

Figure 7 – The 6 DOF Mitsubishi RV-13FM.

Main features of the RV-13FM arm are:

- 6-axis
- Repeatability: ±0,05 mm
- Payload: 13 kg
- Linear Workspace: 1094 mm
- Weight: 120 kg
- real-time path control capability

4 Vision system implementation and testing

The implementation of the circular edge detector and more in general the development of the implemented algorithms devoted to patient eye localization such as filtering, segmentation and as a final point of the development of the circular regression algorithms in order to calculate the equation ellipse best fitting the real welding path (circular corneal wound) and the detection and localization (for tracking purpose) of the laser spot has been realized developing a set of MATLAB functions. These functions can be called and tested by using a prototype GUI as shown in figure 8.

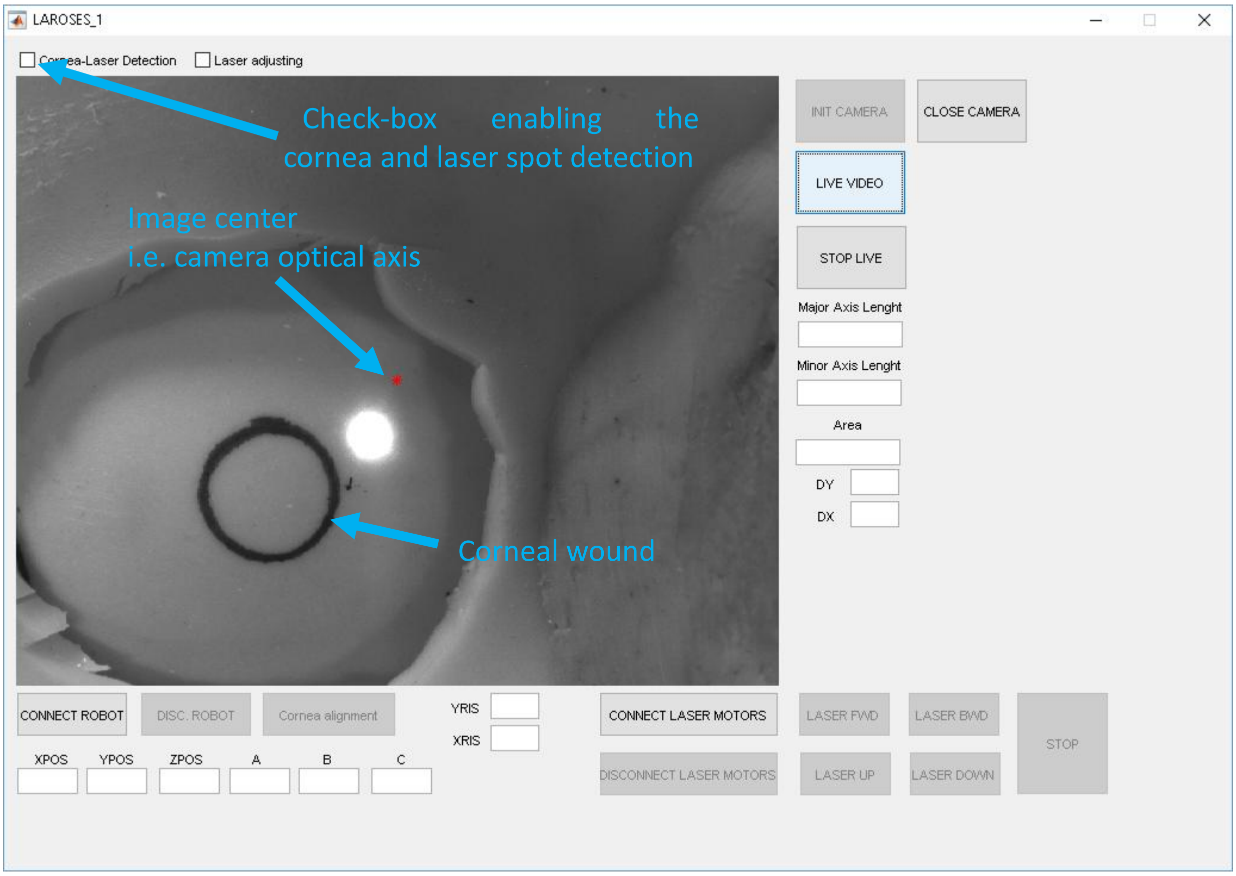


Figure 8 – MATLAB prototype GUI.

The GUI presented in figure 8 includes buttons and procedures to control all LA-ROSES robotic system functionalities including VS closed-loop schemes (VS closed-loop schemes are given in D5_1).

Indeed, the image vision algorithms here described involves the detection of the laser spot and the corneal wound. In particular, the detection of the laser spot gives out the image plane coordinates of the laser spot center whilst the output of the detection of the corneal wound gives out the image plane coordinates of the ellipse best fitting the boundary of the wound. This information is used by the VS procedures to send appropriate motor commands to the LA-ROSES controllers including the controller of the laser handling system and the robot controller in order to carry out the functionalities listed below:

- enabling circular movement of a laser probe allowing a tracking of the circular path marked by the indocyanine solution
- enabling changing laser orientation, altitude from the corneal wound and tracking velocity during the welding procedure
- enabling initial gross and accurate positioning of the laser probe above the patient's eye
- accurate laser probe positioning above the patient's eye
- Through a control loop including the thermal camera, robot and laser intensity, a certain predefined temperature must be achieved on predefined points on the circle
- Demonstration of mitigation in dangerous scenario (e.g. Laser stops if temperature rises beyond certain limit, detected by the integrated thermal camera on end-effector).

These functionalities will be described in detail in D5.1.

The laser spot detection has been developed using morphological operators to separate from the background a blob area similar to a white circle. If a white blob area is detected having its major axis and minor axis like a circle has then the following code provides out the coordinates of its center and its radius.

```
% laser detection
bw_l = im2bw(I,0.95);
str = strel('disk', 3);
bw_l = imerode(bw_l, str);
laser=find(bw_l>0);
[B,L] = bwboundaries(bw_l,'noholes');
stats = regionprops(L,'Centroid','MajorAxisLength','MinorAxisLength','Area','PixelList');

idx_laser = 0;
for i=1:length(B)
   if (abs(stats(i).MajorAxisLength/stats(i).MinorAxisLength)<2.5)
      idx_laser=i;
   end
end

if (idx_laser~=0)
 centro = stats(idx_laser).Centroid;
 laser_cx = centro(1);
 laser_cy = centro(2);
 diametro = mean([stats(idx_laser).MajorAxisLength stats(idx_laser).MinorAxisLength],2);
 raggio = diametro/2;
 %hold on
 h1=viscircles(centro,raggio);
 %hold off
end
```

The cornea detection starts performing a image segmentation using the Canny operator. The Canny operator operates as follows:

- Apply Gaussian filter to smooth the image in order to remove the noise
- Find the intensity gradients of the image
- Apply non-maximum suppression to get rid of spurious response to edge detection
- Apply double threshold to determine potential edges
- Track edge by hysteresis: Finalize the detection of edges by suppressing all the other edges that are weak and not connected to strong edges.

So, at the end of the execution of the Canny operator over an image containing a corneal wound similar to those illustrated in figure 8 the edges of the corneal wound are highlighted so that they can be considered as candidates to be elaborated by a circular regression algorithm. If a circle identifying the corneal wound is found its center coordinates and its radius are provided out. The following MATLAB code implements these steps.

```
% cornea detection
BW = edge(I,'Canny',.3,.4);
CC = bwconncomp(BW);
numPixels = cellfun(@numel,CC.PixelIdxList);
idx=find(numPixels>50);
BW2 = ismember(labelmatrix(CC), idx);
```

```
%figure;imshow(I);

radii = 95:1:110;
h = circle_hough(BW2, radii, 'same', 'normalise');
peaks = circle_houghpeaks(h, radii, 'nhoodxy', 15, 'nhoodr', 21, 'npeaks', 1);
%hold on;
for peak = peaks
   [x, y] = circlepoints(peak(3));
   h2=plot(x+peak(1), y+peak(2), 'g-');
end
if (h2~=0)
   cornea_cx = peak(1);
   cornea_cy = peak(2);
   cornea_r=peak(3);
   h3=plot(cornea_cx,cornea_cy,'y+');
end
```

5 References

Hutchinson, S., Hager, G. & Corke, P. (1996), ‘A tutorial on visual servo control’, IEEE Transactions on Robotics and Automation 12(5), 651–670.